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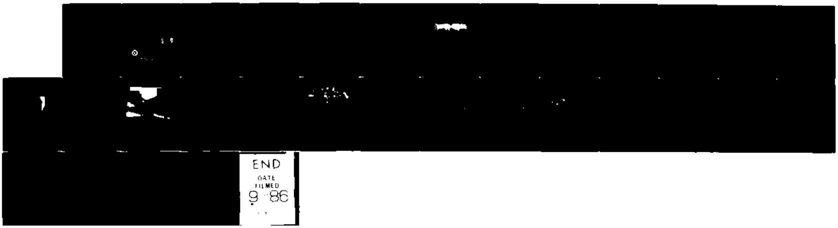

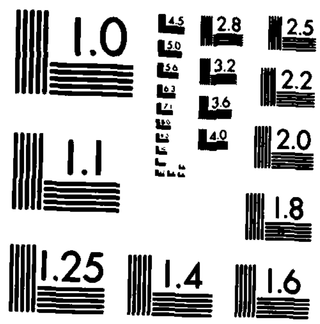

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7 July 1986

Comparison Between the North and South Pacific Oceans of Acoustic Propagation in Secondary Sound Channels

A Paper Presented at the International Conference on Developments in Marine Acoustics, Sydney, Australia, 4 December 1985

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PREFACE

This work was accomplished under NUSC Project No. A65000, "EVA Support for Shipboard Sonar," P. D. Herstein (Code 33A3), Principal Investigator. Funding was provided under Program Element No. 62759 through the Naval Research Laboratory, L. Bruce Palmer, Acting Program Manager of EVA Support for Shipboard Sonar.

REVIEWED AND APPROVED: 7 July 1986

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This document is a summary of the extent and causes of secondary sound channel formation in the Pacific Basin. In the North Pacific above 40° North latitude and in the Western Pacific near the equator, both regions where the average precipitation is greater than evaporation, secondary sound channels due to temperature inversions are found over extensive areas. In the Central South Pacific and to a lesser extent in the Subantarctic region, secondary sound channels are principally caused by water mass intrusion. A third mechanism, circulation instability, is found locally near major currents and outflows throughout the Basin.

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SECONDARY SOUND CHANNEL FORMATION: A COMPARISON BETWEEN THE NORTH PACIFIC AND SOUTH PACIFIC OCEANS.

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NEW LONDON, CT 06320 U.S.A.

SLIDE 1

In this paper I will try to give a brief overview of the location, causes, and duration of secondary sound channel (SSC) formation throughout the Pacific Basin. The South Pacific work was done with the New Zealand Defence Scientific Establishment; the North Pacific work was done with the Canadian Defence Research Establishment-Pacific. However, I am solely to blame for any overstated generalities. Since there has been significant work done in this area here in Australia, I would appreciate any further insight that you would like to share.

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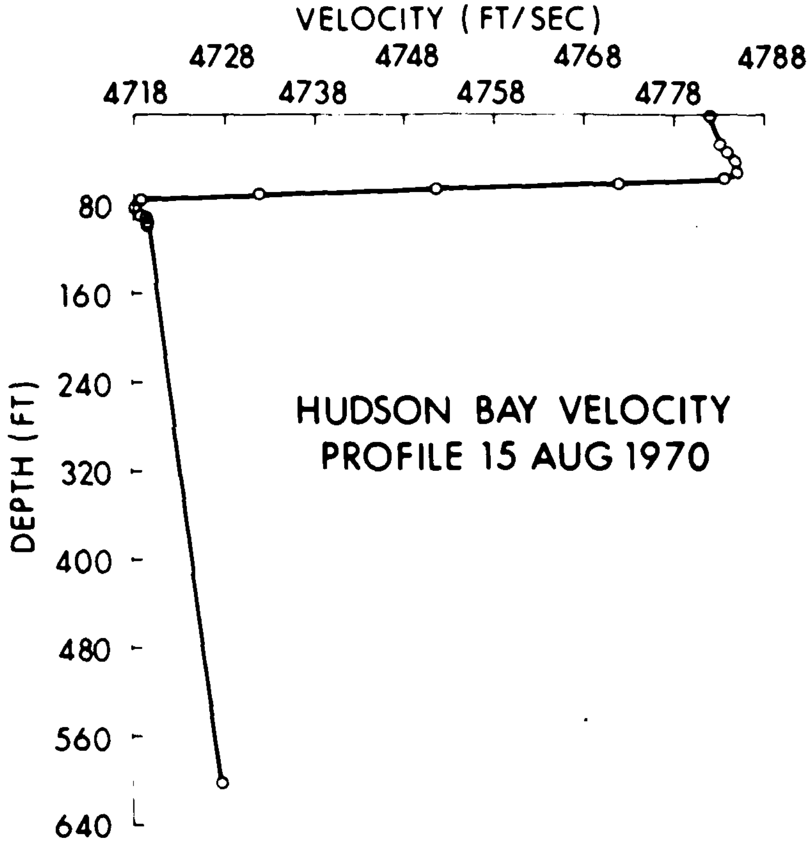

SLIDE 2

For those not familiar with underwater sound propagation, your first question might be: "What is an SSC secondary to?" The answer is that throughout most of the ocean basins there exists a deep sound channel (DSC) with an axis depth of typically 1000 meters. Here we have a relatively shallow DSC in Hudson Bay, Canada. The upper gradient is due to surface heating, the lower gradient is due to the cumulative effect of pressure.

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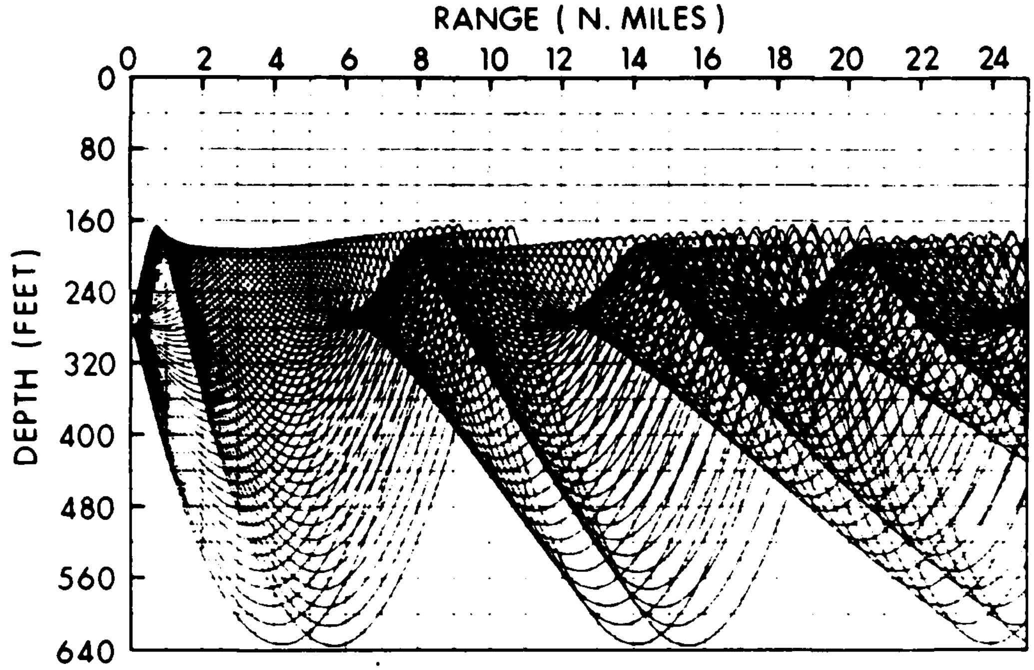

SLIDE 3

If a sound source were placed at the sound channel axis (depth of minimum sound speed), some of the ray paths would be continually refracted about the axis. Since they strike neither the surface nor bottom, the only real loss is due to absorption by sea water, a small quantity at low frequencies. Hence it is possible to transmit sound over thousands of kilometers in the ocean.

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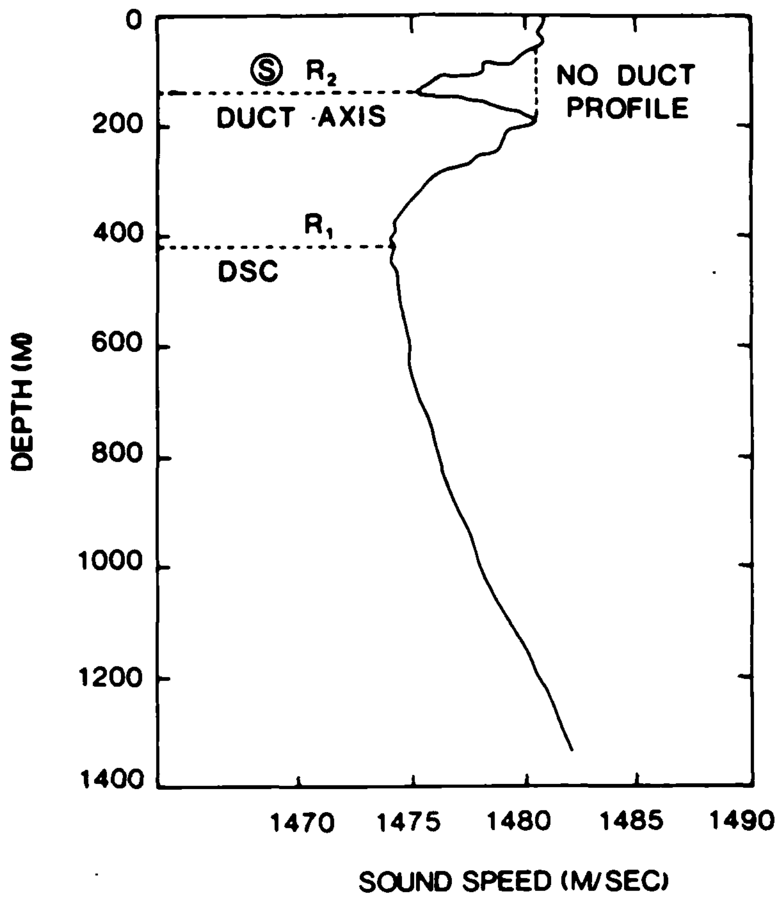

SLIDE 4

If we have this excellent DSC, why would we be interested in smaller, shallower secondary channels? The principal reason is that in some practical cases the DSC axis is too deep to be reached, but we can reach the axis of a secondary channel. The uniform coverage of axial rays in the SSC outweighs the disadvantages of weakness and variability of the SSC because the off-axis, hence, convergence zone, coverage in the DSC is not uniform.

I should note that authors use various terms for what I call SSC, i.e., shallow sound channels, secondary ducts, and perhaps most frequently when the SSC is only a half channel it is called a surface duct. It's all the same and I don't claim my notation is any better than the others.

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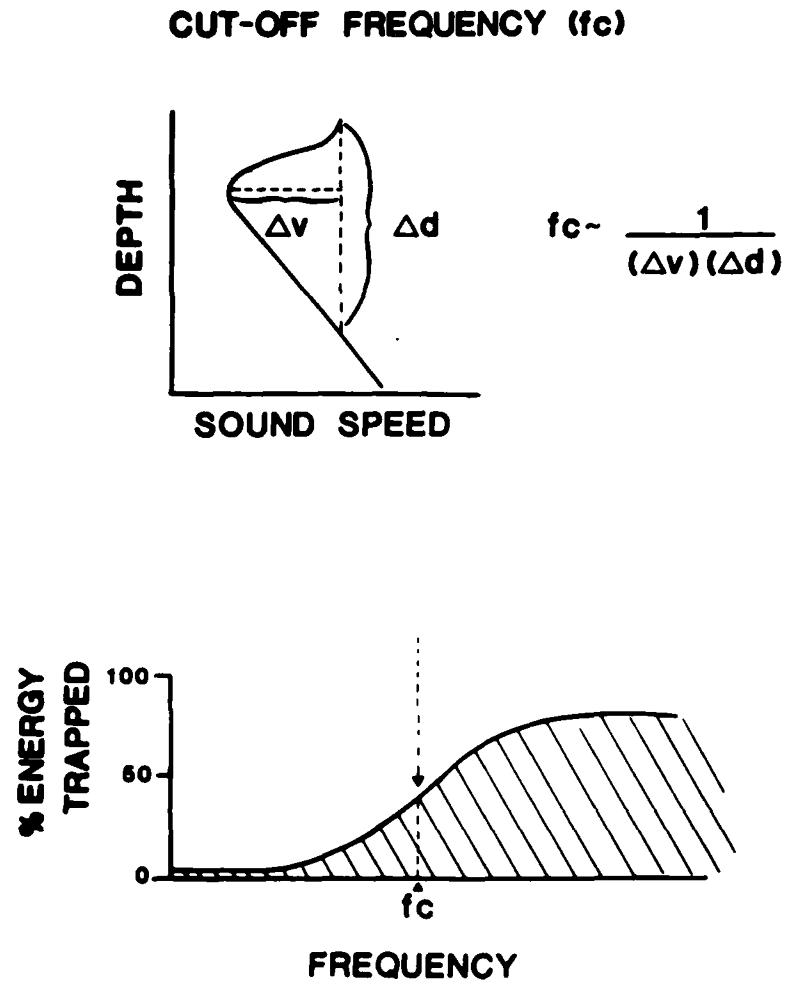

SLIDE 5

The strength or weakness depends on two factors, the height and width. A practical measure is the cutoff frequency -- the frequency below which energy is no longer trapped in a channel (the stronger the channel the lower the cutoff frequency). A representative value for the DSC would be 4 Hz, while observed values for SSC range from 100 to 1000 Hz or higher.

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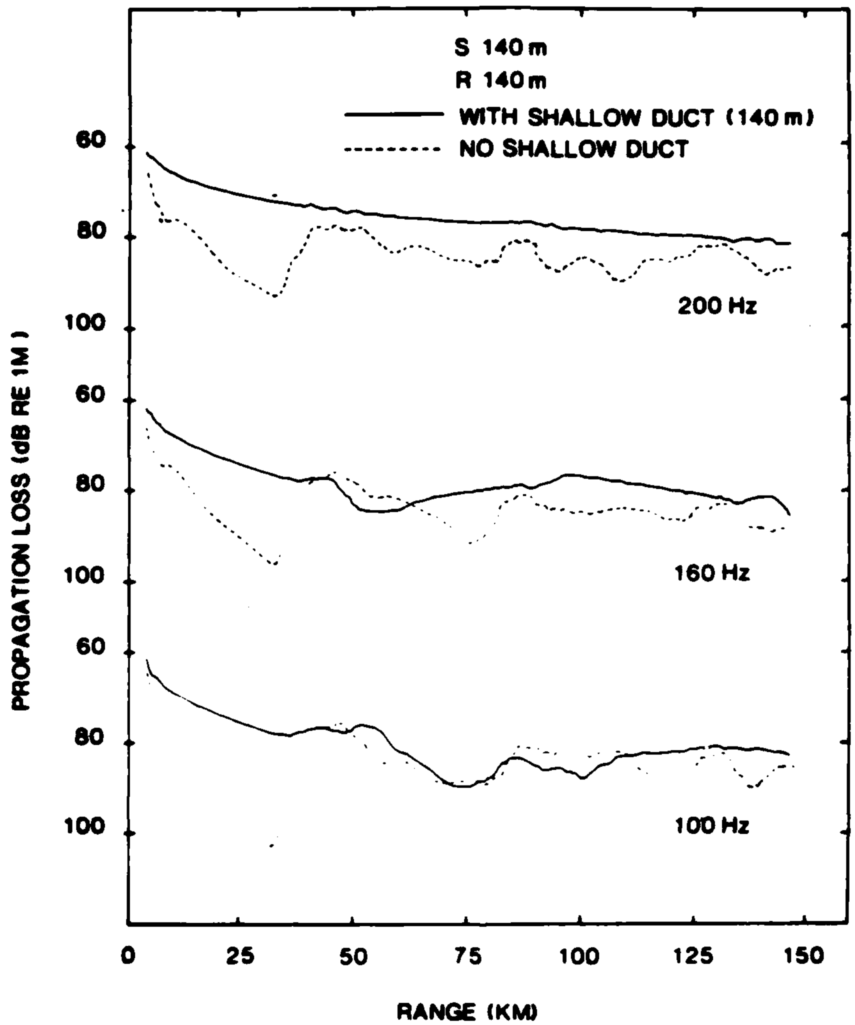

SLIDE 6

To illustrate, we show some modeling results for an SSC with a cutoff frequency of 100 Hz. We compare results for a sound speed profile with an SSC with a profile without an SSC. Both source and receiver are of the depth of the SSC axis. At frequencies above the cutoff frequency, energy is efficiently trapped in the SSC giving cylindrical spreading loss. With no SSC we have less efficient (at most ranges) off-axis convergence zone propagation. As the frequency is lowered, trapping by the SSC becomes less efficient.

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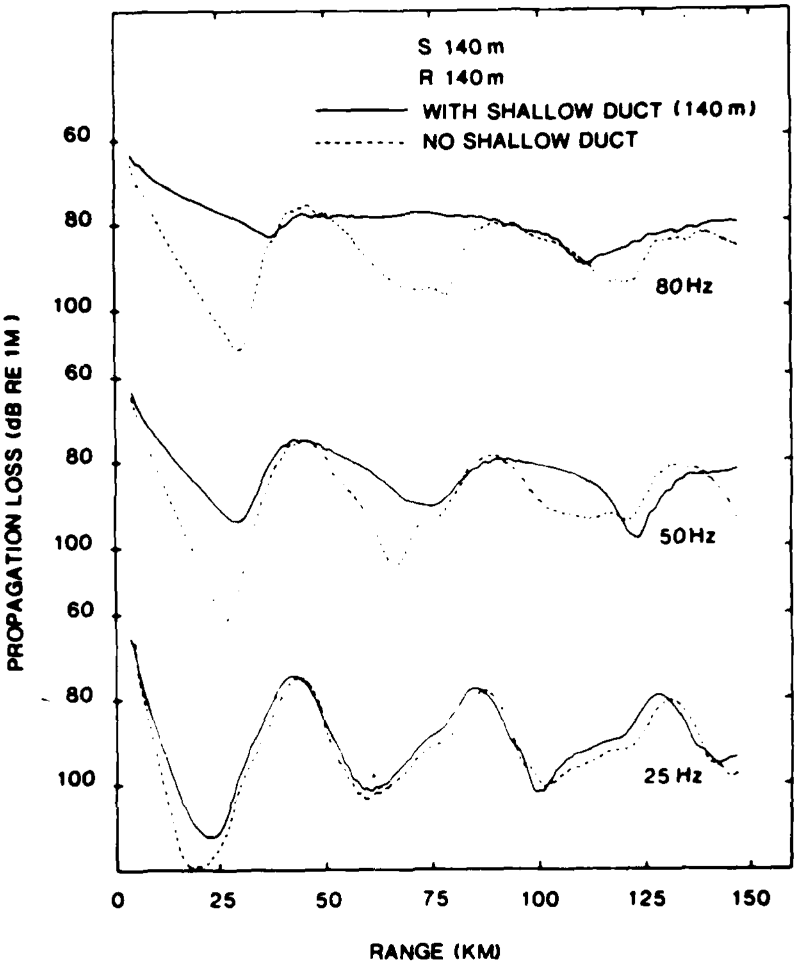

SLIDE 7

As the frequency is lowered to below the cutoff frequency the SSC becomes ineffective with essentially no trapped energy. Hence, the propagation loss curves with or without the SSC are essentially the same.

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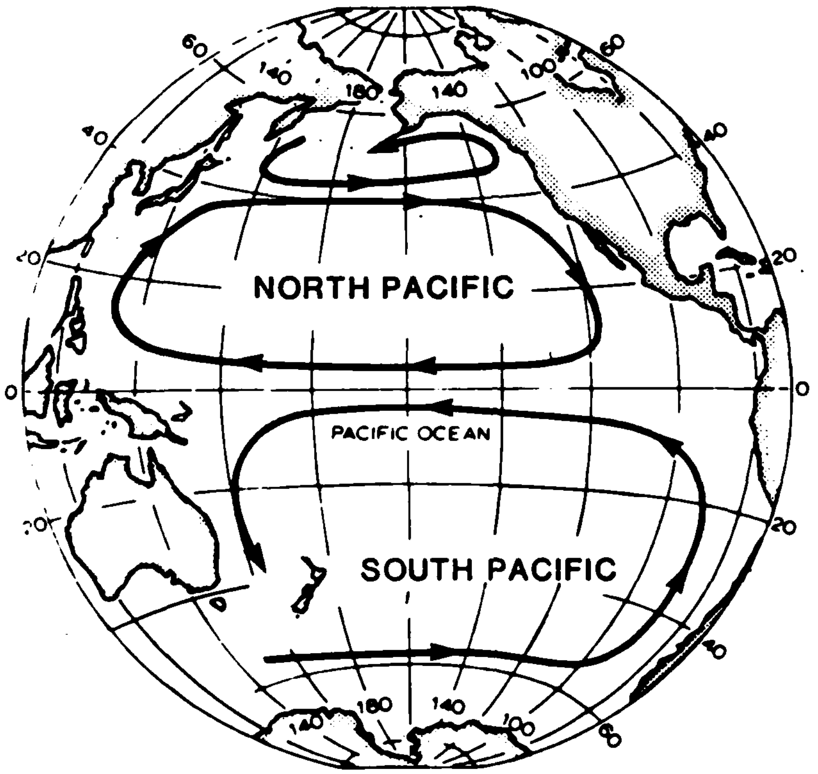

SLIDE 8

To determine the causes of SSC formation, let's examine the general circulation pattern in the Pacific Basin. In the South Pacific there is one principal circulation gyre driven by the antarctic circumpolar current. This gyre is the dominant factor in SSC formation. In the North Pacific the principal gyre extends to only 40° N latitude and is not a major cause of SSC formation, which occurs mainly in the subarctic circulation to the north of the main gyre.

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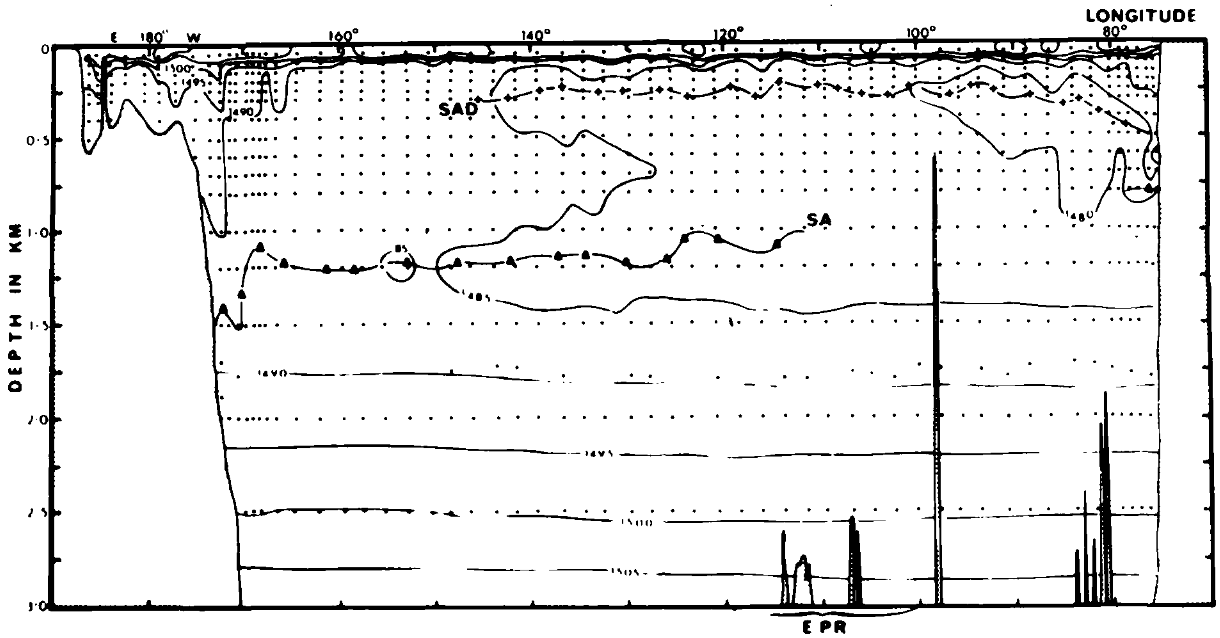

SLIDE 9

In the South Pacific this oceanographic cross-section, taken at 43° S latitude by the Scorpio Expedition and converted to sound speed by Ron Denham (New Zealand DSE) shows the impact of circulation on SSC formation. Along the South American coast (on the right) the cold water with a shallow DSC axis totally displaces the subtropical water that has a DSC axis at 1000 meters. Further away from the coast, however, the cold water mass only intrudes into the subtropical water, resulting in the formation of an SSC. On the left, the flow of the subtropical water downward along the Australian coast results in only the DSC axis at this latitude.

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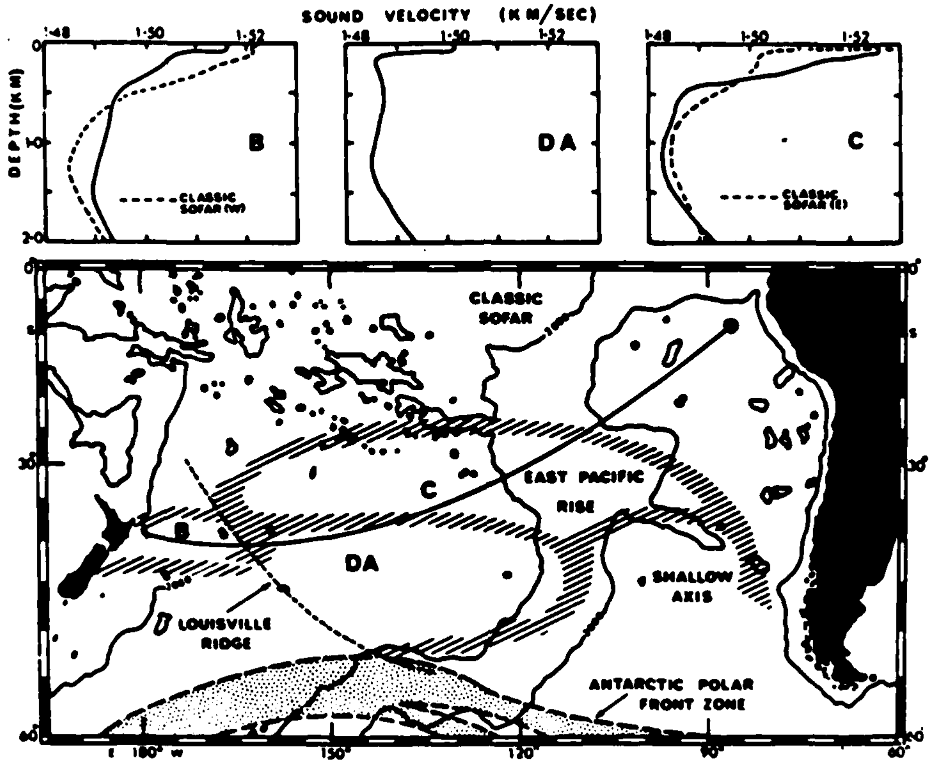

SLIDE 10

Denham and others have shown the extent of this region, which comprises a major segment of the South Pacific, and is indicated here by the notation DA for double axis. The corresponding profile is in the center of the top line.

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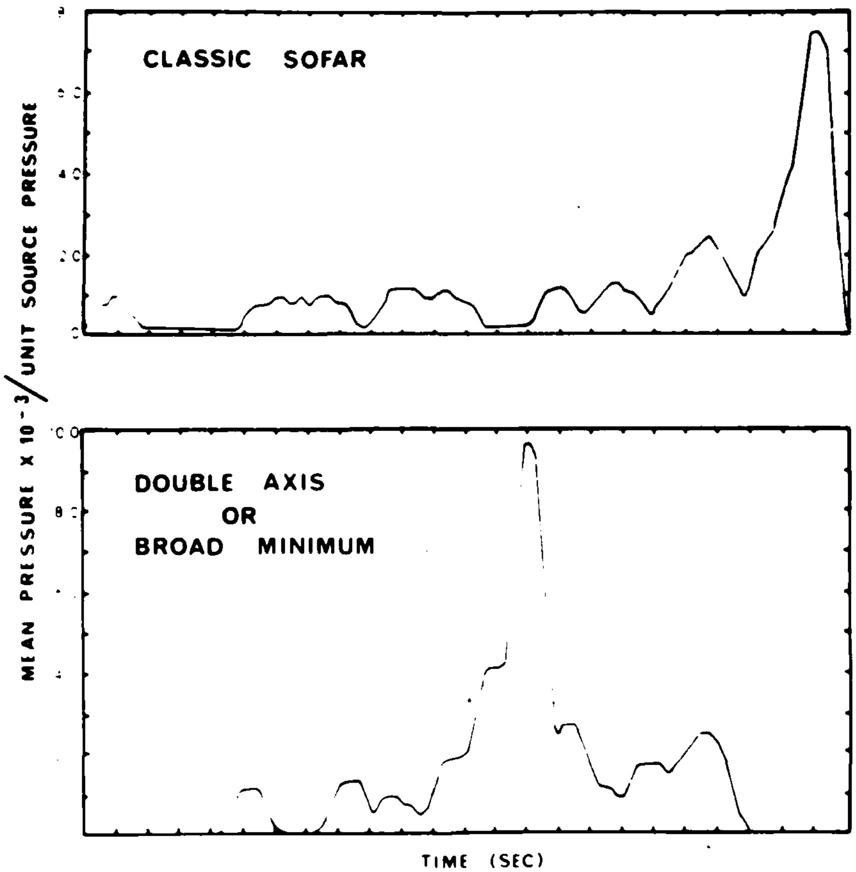

SLIDE 11

While a student of Kibblewhite at the University of Auckland, Guthrie showed, in what is now regarded as a benchmark paper, that the arrival structure for such a double-axis profile would be significantly different than classic sound speed profile observed throughout large regions of the North Atlantic and Pacific.

Specifically, the acoustic energy associated with the axial ray, which arrives last with the classic profile, arrives in the middle of the pack with the double axis profile.

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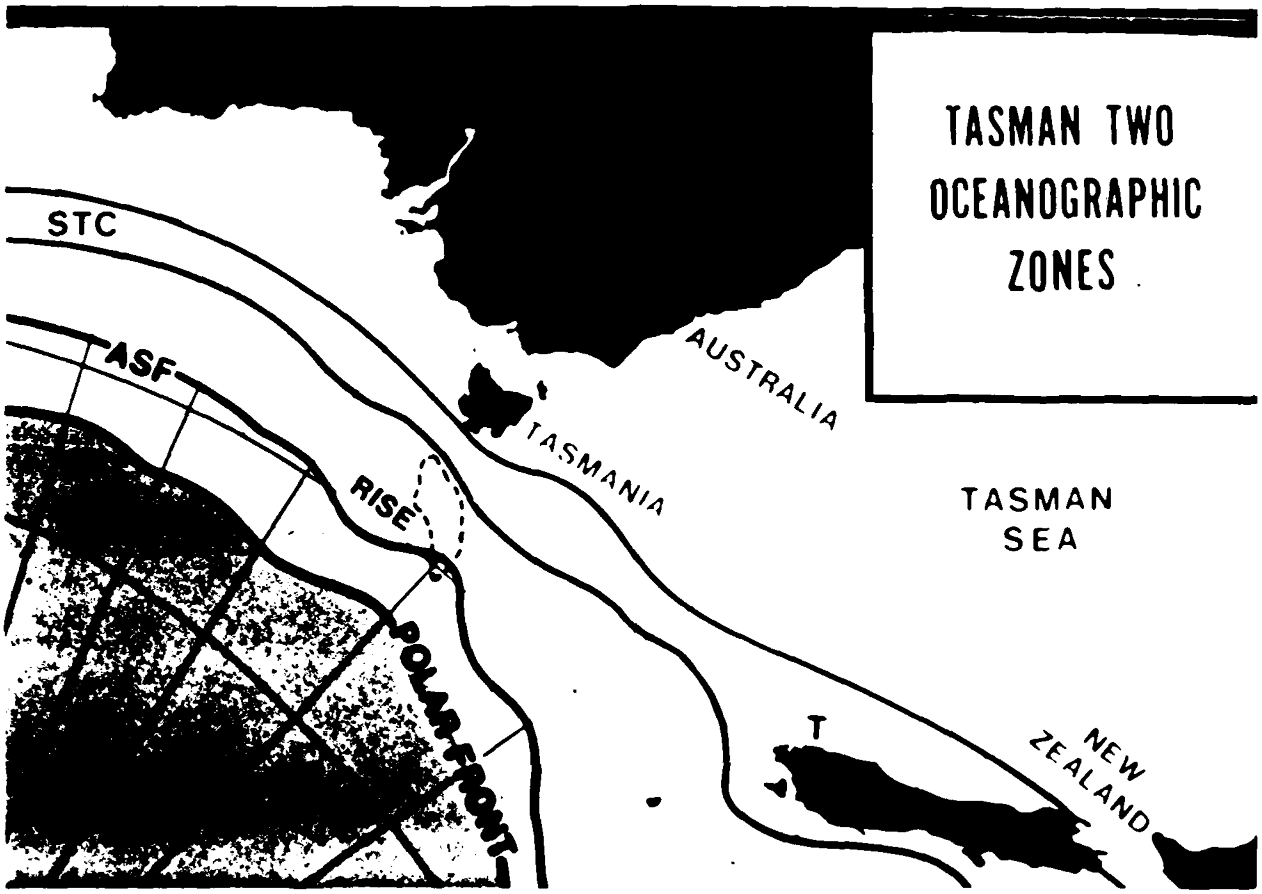

SLIDE 12

Before the cold water swings northward along the South American coast, the influence of the Antarctic circumpolar current is confined to higher latitudes and results in a rapidly changing series of fronts and convergences as one moves to the North.

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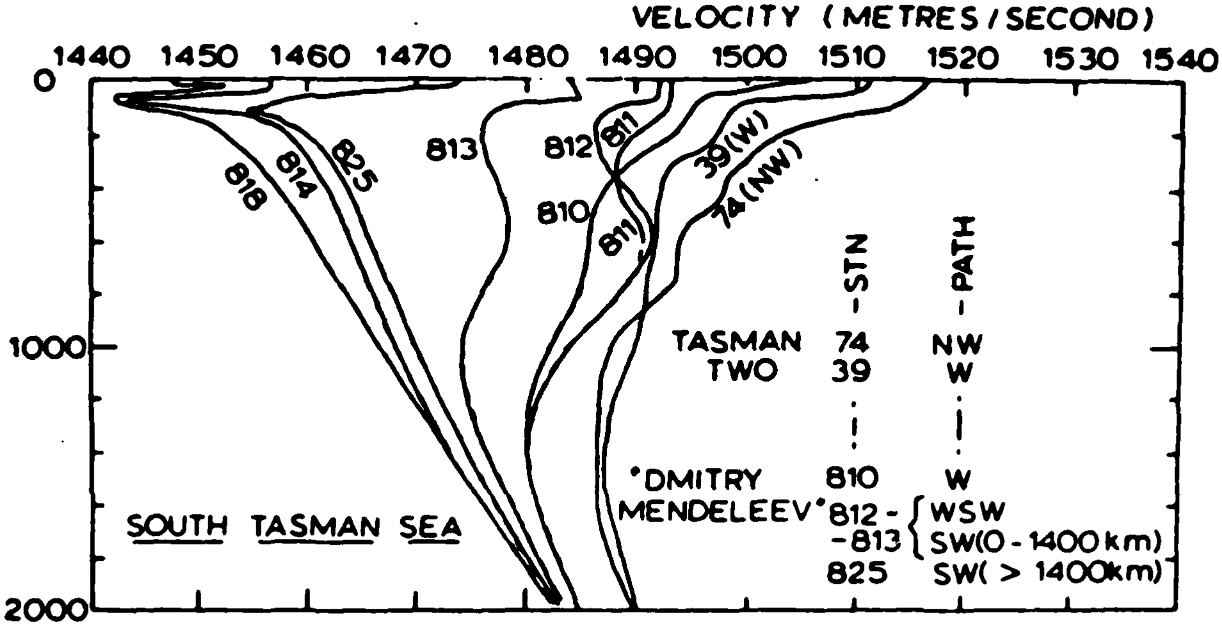

SLIDE 13

Kibblewhite, et al., have conducted a sound speed profile cross-section through this region. As you can see, there is a relatively narrow band where a SSC occurs, the result of water mass intrusion, specifically the profile numbered 813 forms a rather abrupt boundary between typically Antarctic profiles to the left and subtropical profiles to the right.

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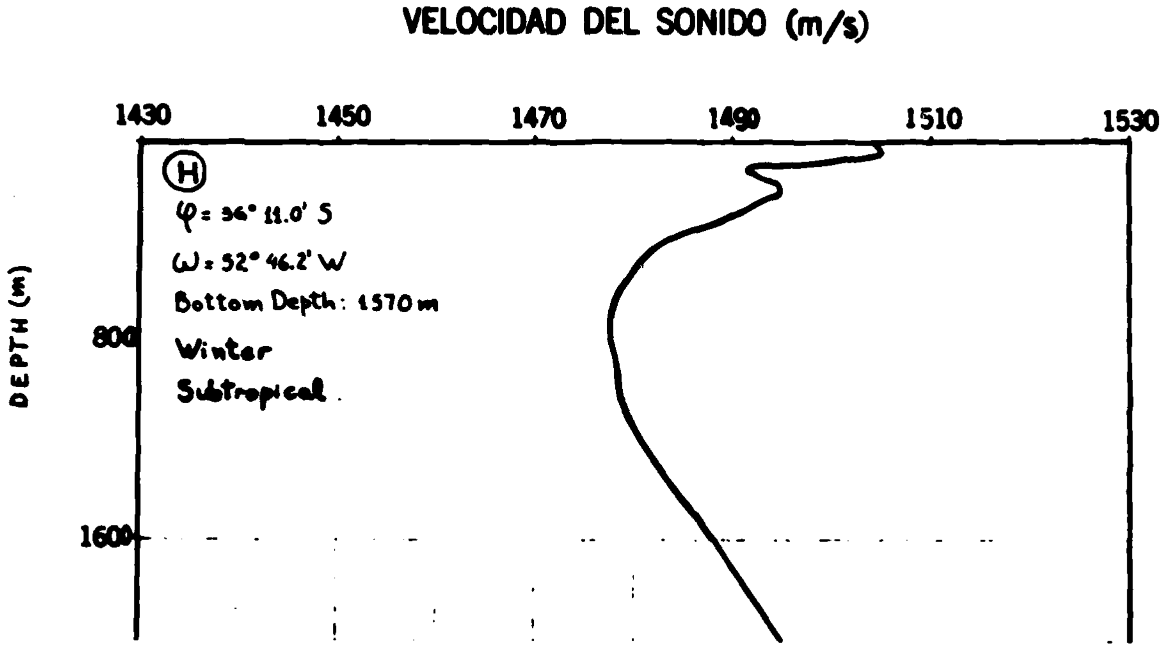

SLIDE 14

To illustrate the world-wide impact of the cold water intrusions caused either directly or indirectly by the Antarctic circumpolar current, here is a profile from the South Atlantic also showing SSC caused by cold water intrusion into a subtropical water mass.

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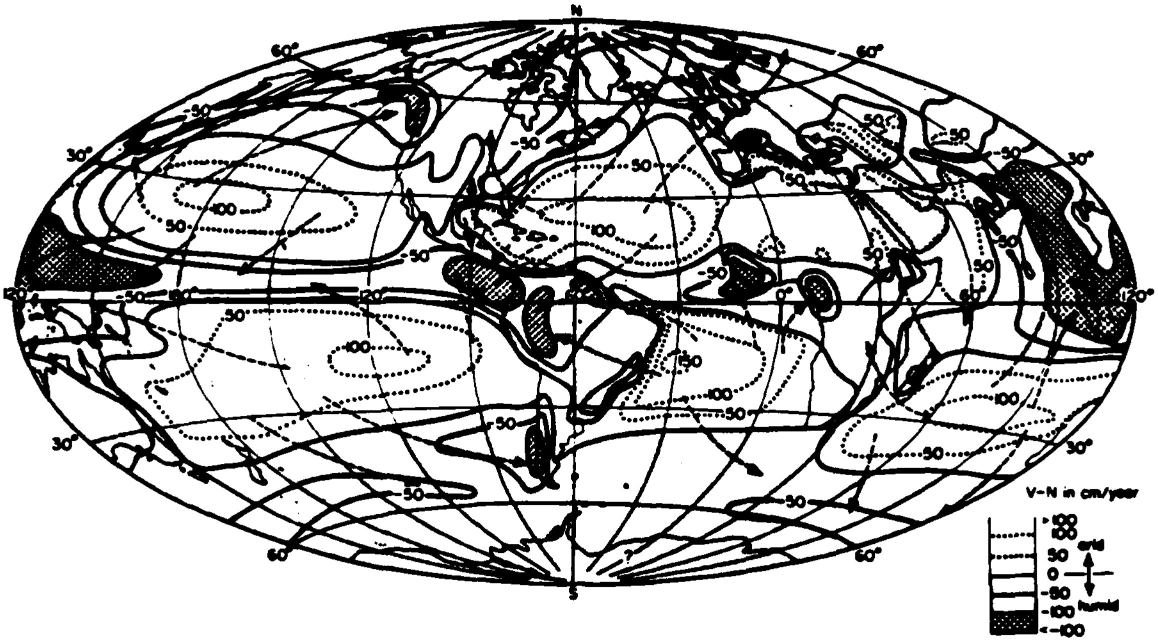

Annual mean distribution of the amount of evaporation minus precipitation (in cm. per year) at the earth's surface and mean direction of the water vapor transport in the atmosphere. (Based on F. Albrecht, 1947, 1951; W. C. Jacobs, 1951.)

SLIDE 15

Another factor in the formation of SSC is the existence of a permanent, reduced salinity, surface layer that is caused by a net influx of fresh water (more precipitation than evaporation). This map shows that this condition is usually met near the equator (high evaporation but even higher precipitation) and in the subarctic regions (low evaporation, moderate precipitation). The temperate zones, in general, do not meet this condition.

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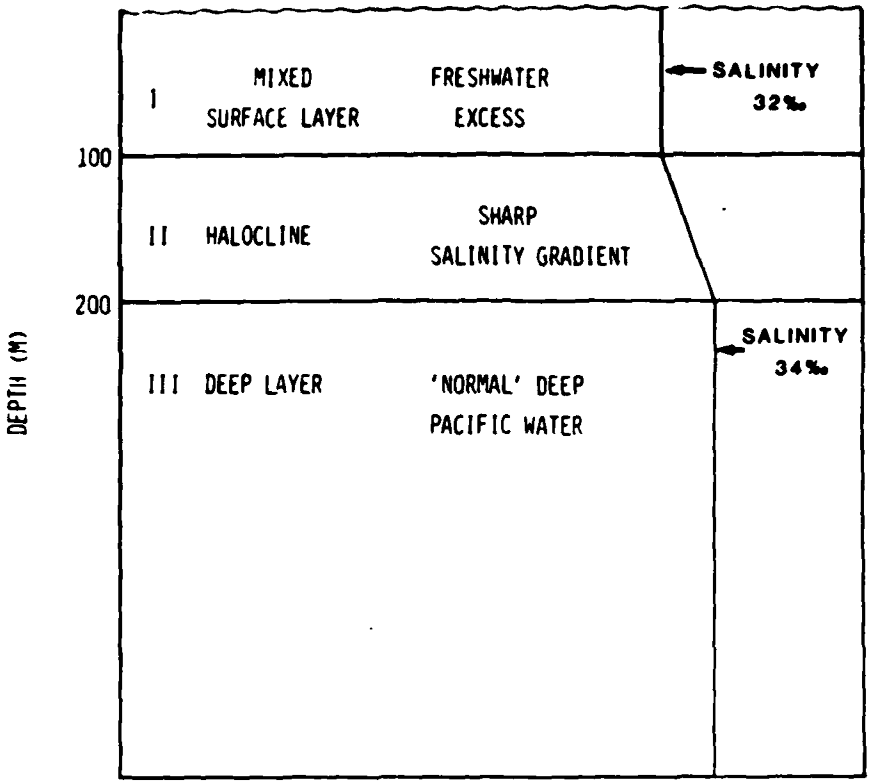

SLIDE 16

The fresh water excess produces a reduced salinity layer typically 100 meters thick. This suppresses and compresses the normal halocline that is a barrier to deeper surface heating. As a result, the surface layer acts as an independent shallow water system isolated from the rest of the water column. Conversely the deep water column is isolated from solar heating and is controlled by circulation.

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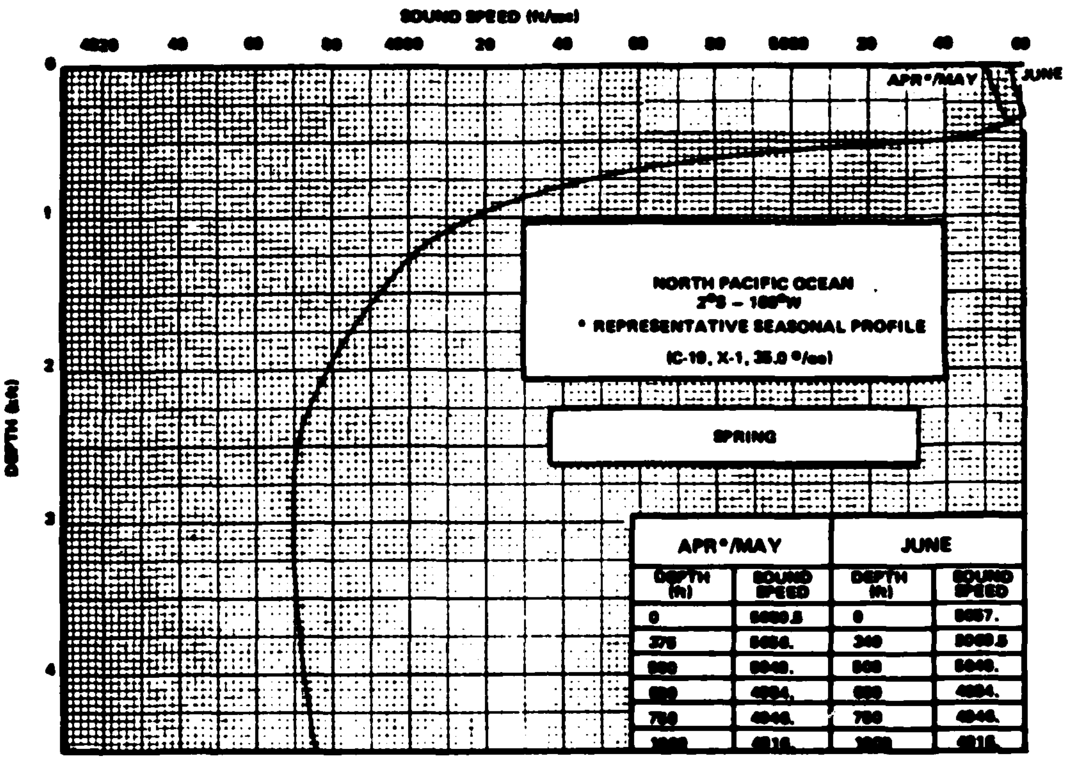

SLIDE 17

In the tropics this surface layer persists as a temperature mixed layer throughout the year, resulting in a permanent secondary half-channel or surface duct. This is an example from the Bismarck Sea (for spring conditions), the situation is similar in both the North and South equatorial Pacific.

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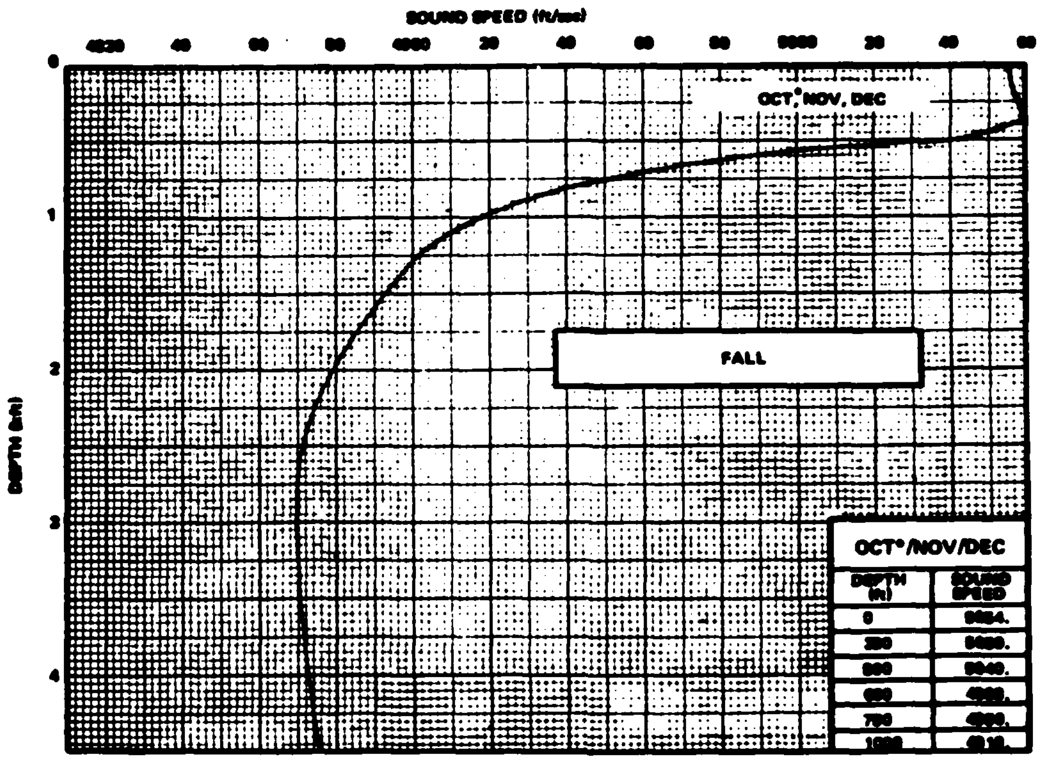

SLIDE 18

Here is the same situation for fall conditions and you can see that the surface duct persists.

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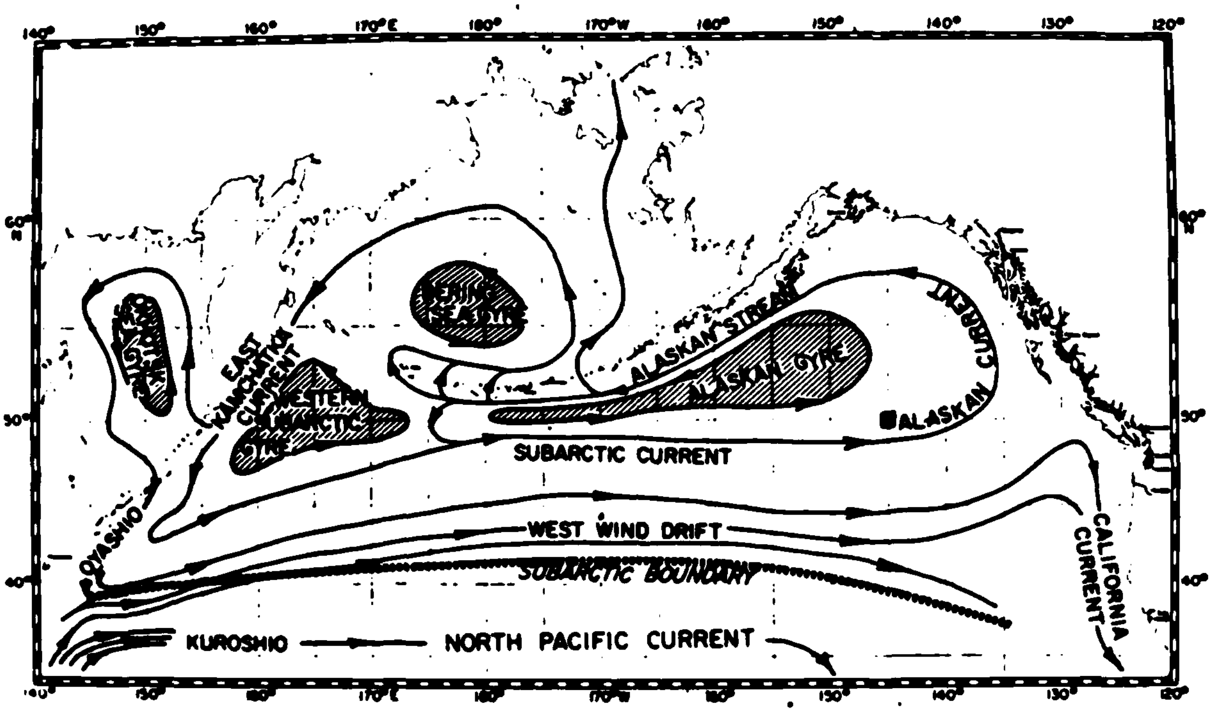

SLIDE 19

In the Subarctic North Pacific we have an interesting and significant variation on this same theme. The Subarctic North Pacific is an ideal location for SSC formation due to its fresh water excess and isolation from the main circulation gyre. It stretches across the entire North Pacific covering all the area above 40° N latitude, stretching from the subarctic boundary to near the Bering Strait.

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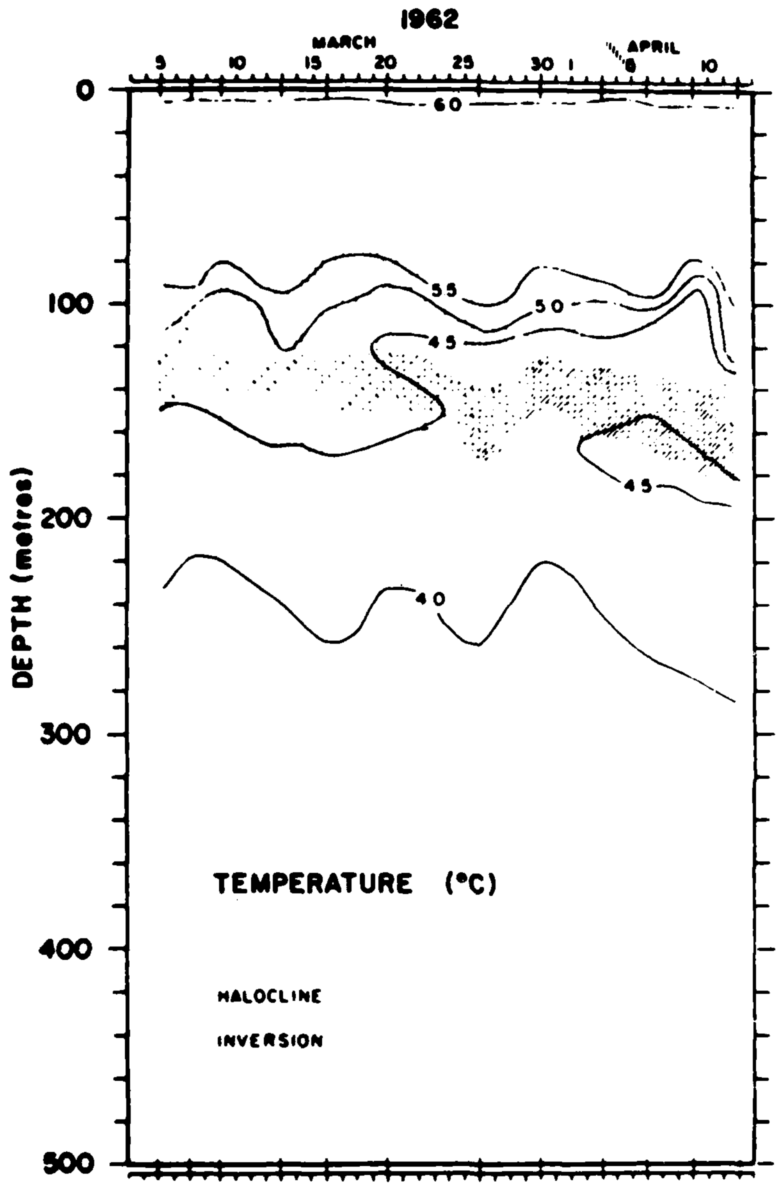

SLIDE 20

Throughout this region we have an interesting yearly cycle. During the winter, storms cause the surface layer to have a uniformly cold temperature, colder in fact than the deep water layer below, which is insulated by the halocline. When summer comes, surface heating takes place creating a temperature gradient. However, the influence of this heating does not extend to the bottom of the surface layer. We are, therefore, left with a temperature inversion, the remaining cold water from winter, at the bottom of the layer. Here is shown typical data from weather ship "Papa" that was located in the subarctic region and obtained continuous data for almost twenty years.

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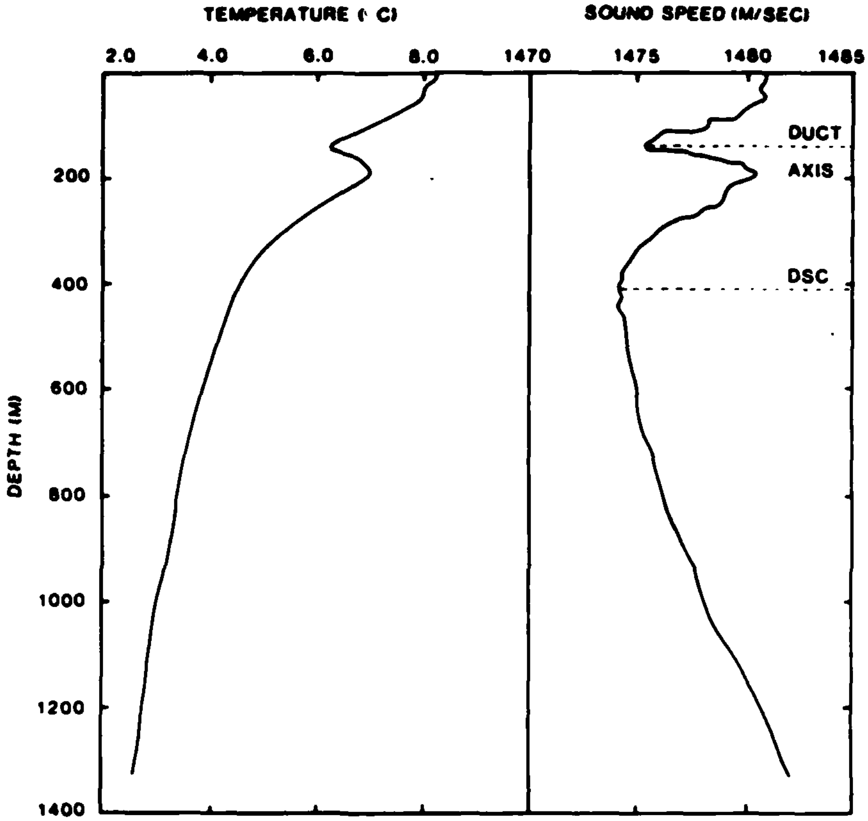

SLIDE 21

This temperature inversion causes the formation of a true SSC as this comparison of the temperature and sound speed profiles shows. In this case the SSC axis is around 100 meters deep and the DSC axis about 400 meters.

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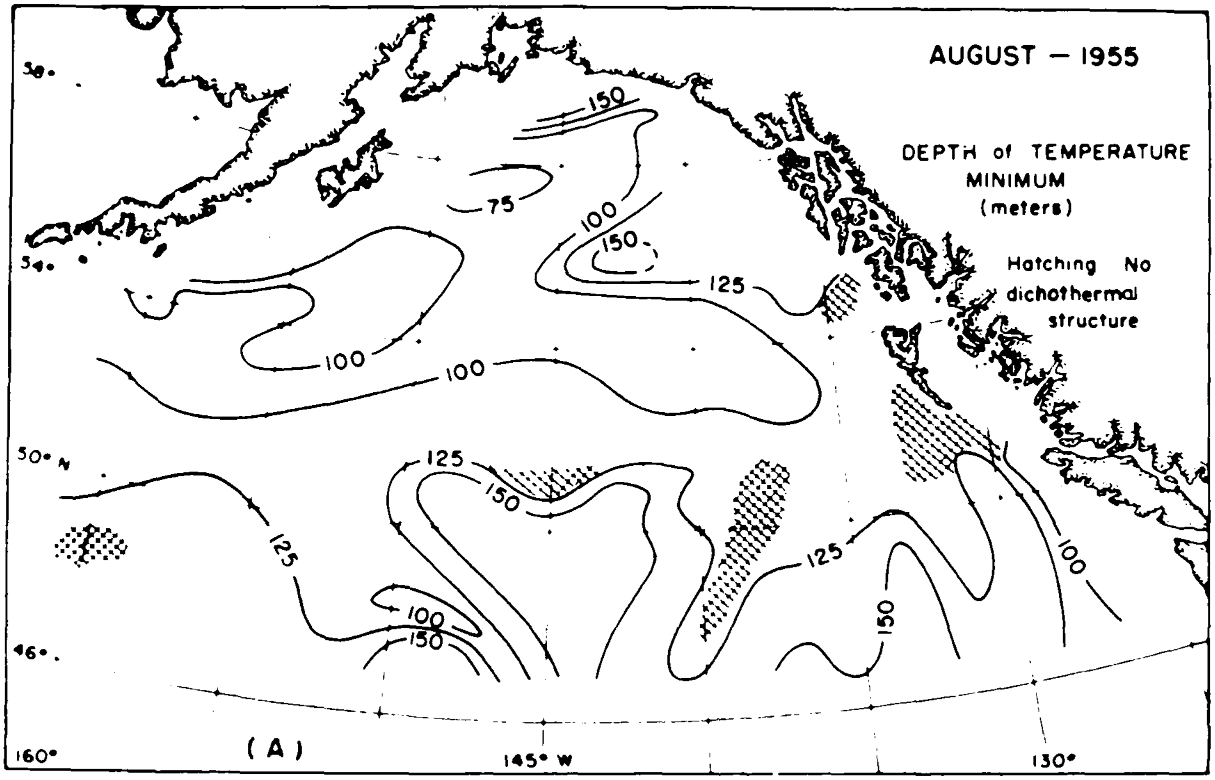

SLIDE 22

The extent and relative uniformity throughout the subarctic region is illustrated by this map of the Northeast Pacific region for a given year. The hatched areas are the only places where the inversion did not occur.

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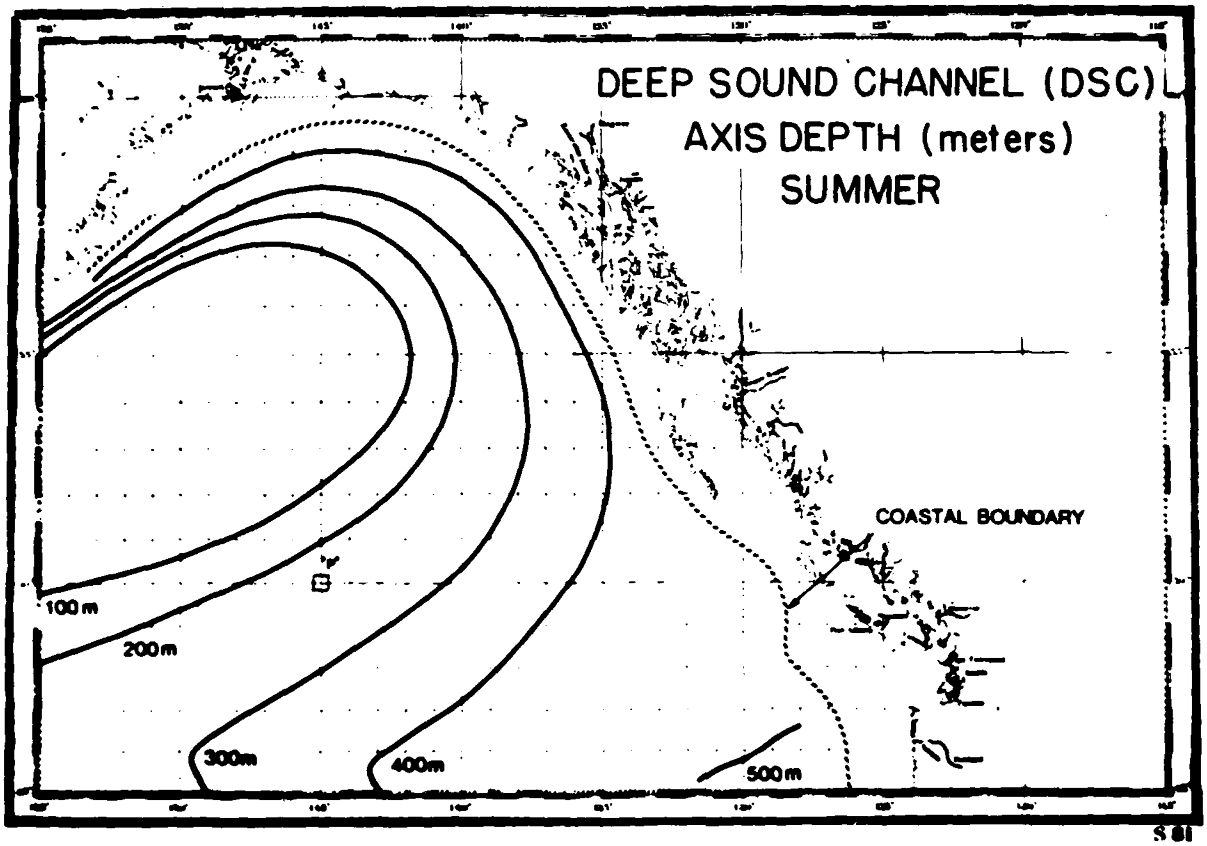

SLIDE 23

As an aside, I mentioned that the other side of the coin in this situation was that the DSC was insulated from surface heating. Here we see confirmation of this. The DSC axis depth is related directly to the circulation pattern rather than generally decreasing at higher latitudes, as would be the effect of solar heating, forming concentric rings about the Alaskan gyre, which is the primary circulation feature in the Northeast Pacific.

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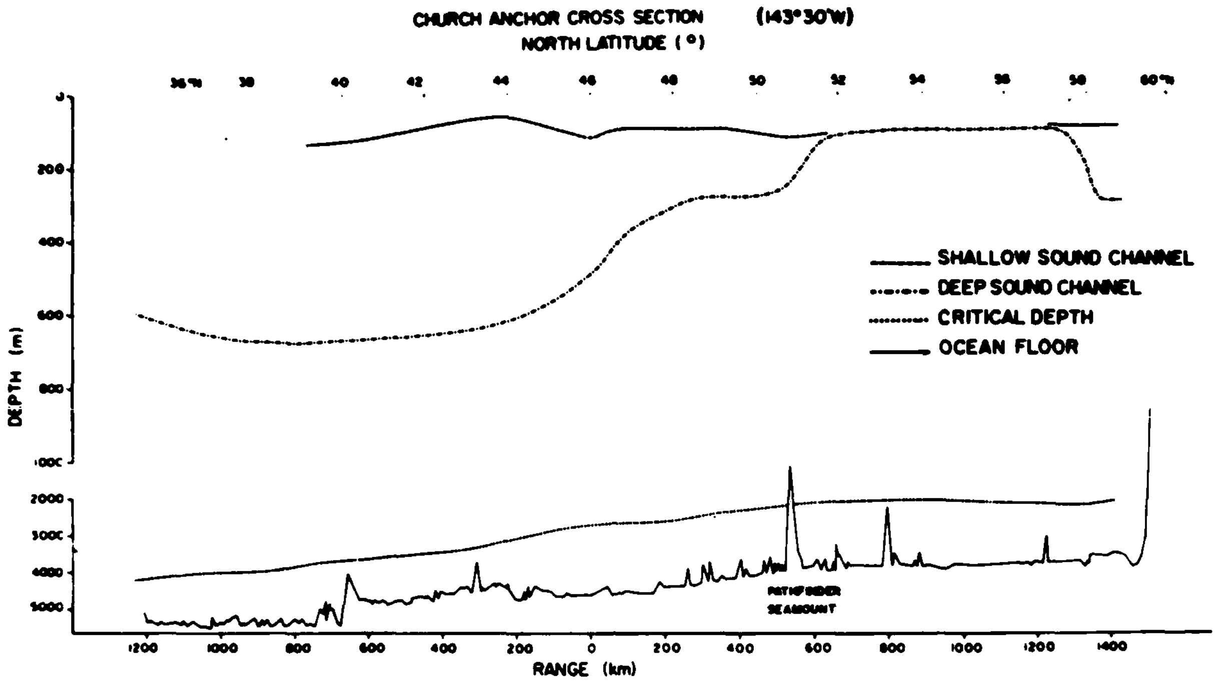

SLIDE 24

The independence of the SSC and DSC formation processes results in a very interesting situation, as this south to north cross-section taken during Project Church Anchor shows. The SSC is at a constant depth, while the depth of the DSC decreases to the center of the gyre, then increases again. Marshall Hall at Royal Australian Navy Research Laboratory and the group at the Naval Ocean Systems Center have been pioneers in studying the effect of one channel on another and this might provide an interesting case for them.

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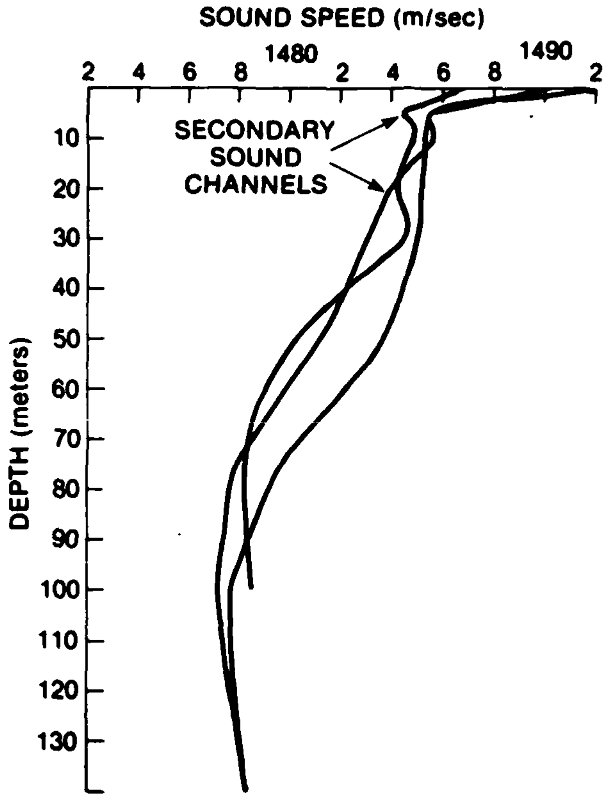

SLIDE 25

The last mechanism I would like to illustrate is circulation instabilities. These are the most transient of SSC's and the least known. Shown here are a series of profiles taken about 10 km apart in a region of strong flow. Transient SSC's are formed that do not appear to correlate over large distances. It would be expected that these may be found near major currents or regions of constricted flow.

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SUMMARY

- THREE PRINCIPAL CAUSES OF SECONDARY SOUND CHANNELS:
  1. SURFACE LAYER/TEMPERATURE INVERSION
  2. WATER MASS INTRUSION
  3. CIRCULATION INSTABILITIES

- DOMINANT MECHANISMS:

  NORTH PACIFIC - TEMPERATURE INVERSIONS

  SOUTH PACIFIC - WATER MASS INTRUSION

SLIDE 26

In summary, we have identified three principal causes of SSC's that cover a significant area of the Pacific Ocean, i.e.,

1. surface layer/temperature inversion,
2. water mass intrusion, and
3. circulation instabilities.

We believe the dominant mechanisms are

North Pacific: temperature inversions and
South Pacific: water mass intrusion.

We would appreciate any inputs you might have from your experiences.

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